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NASA

TECHNICAL NOTE
D - 225

SUBSONIC WIND-TUNNEL INVESTIGATION OF THE AERODYNAMIC

EFFECTS OF PIVOTING A LOW-ASPECT-RATIO WING

TO LARGE YAW ANGLES WITH RESPECT TO

THE FUSELAGE TO INCREASE

LIFT-DRAG RATIO

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

WASHINGTON   March 1960

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SUMMARY

An investigation has been made with a fuselage in combination with low-aspect-ratio wings of various plan forms to determine the effects of pivoting the wing as a unit to extreme angles in the yaw direction with respect to the fuselage to increase its aspect ratio. An arrangement of this type has been suggested as a possible means of reducing the high sinking speeds and improving the landing characteristics of airplanes having wings of very low aspect ratio for flight at hypersonic speeds. Three wing plan forms were tested - a delta, a diamond, and a rectangle - with the wing pivoted at angles between the wing and fuselage center lines from 0° to 109°. The investigation was made in the Langley high-speed 7- by 10-foot tunnel at a Mach number of about 0.4 and a Reynolds number (based on fuselage length) of about 3×10^6. Lift, drag, pitching-moment, and rolling-moment data were obtained through an angle-of-attack range of -4° to about 24°. The effects of varying the wing pivot-point location for the delta-wing model were determined, and the delta-wing model was tested with the forward portion of the wing deflected about its center line for roll control and also with a horizontal tail added to the rear of the fuselage.

The results of the investigation indicated that low values of lift-curve slope and maximum lift-drag ratio inherent in the low-aspect-ratio plan forms could be increased by pivoting the wing. The trends in lift-curve slope were in general agreement with those expected from aspect-ratio considerations. Pivoting the wing generally had little effect on the static longitudinal instability of the delta-wing model with pitching moments referred to the wing pivot point, and a stable pitching-moment variation was obtained by adding a horizontal tail. The longitudinal instability of the diamond- and rectangular-wing models was decreased by pivoting the wing. The delta wing pivoted at 67 percent of the wing root chord could be trimmed laterally for pivot angles of 45° and 90° by deflecting the tip area about its center line.

INTRODUCTION

The landing problem associated with very high-speed airplanes can to a large extent be attributed to the low aspect ratio of the wings employed by these aircraft. The problem is especially severe for configurations proposed for the hypersonic flight region (for example, see ref. 1), where wings with aspect ratios of 1.0 or less are considered. One possibility that has been suggested to alleviate the landing problem is that of yawing the low-aspect-ratio wing to extreme angles with respect to the fuselage so that the landing configuration would resemble a relatively large-aspect-ratio airplane. This landing configuration would have desirable lift and drag characteristics and would also provide a good foundation for building an effective high-lift system. Stability and control problems involved in such a maneuver might, of course, offset some of the advantages to be gained. An investigation was made, therefore, to evaluate the feasibility of such a maneuver.

The wing-fuselage combinations used in this investigation were tested with the wing pivoted on the fuselage at extreme angles of yaw while the fuselage remained unyawed with respect to the airstream. These models were intended to give an indication of the stability and control problems involved in the yawed-wing scheme rather than an accurate determination of the aerodynamic improvements to be gained. Three flat-plate wing plan forms were tested - a delta, a diamond, and a rectangle. Some aerodynamic characteristics of rectangular wings at hypersonic speeds are presented in reference 2. Effects of wing pivot-point location and of the addition of a horizontal tail were investigated with the delta configuration. In addition, the delta configuration was tested with the forward portion of the wing deflected about its center line to give roll control during and after transition from high-speed configuration to low-speed configuration.

SYMBOLS

The forces and moments were measured with reference to a body-axis system with the longitudinal axis along the fuselage center line remaining unyawed for all tests. Pitching-moment coefficients are referred to the wing pivot point in all cases and are based on the mean aerodynamic chord of the wing in the conventional unyawed position. Likewise, rolling-moment coefficients are based on the span of the wing in the unyawed position.

b   wing span (0.608, 0.406, and 0.305 ft for the delta, diamond, and rectangular plan forms, respectively)

C_D drag coefficient, D/qS

C_L — lift coefficient, L/qS

$C_{L\alpha}$ — lift-curve slope per deg

C_l — rolling-moment coefficient, $\dfrac{\text{Rolling moment}}{qSb}$

C_m — pitching-moment coefficient referred to wing pivot point, $\dfrac{\text{Pitching moment}}{qS\bar{c}}$

$\bar{c}$ — wing mean aerodynamic chord (1.150, 1.532, and 1.823 ft for the delta, diamond, and rectangular plan forms, respectively)

c_r — wing root chord, ft

D — drag, lb

L — lift, lb

q — dynamic pressure, $\rho V^2/2$, lb/sq ft

S — wing area, sq ft

V — airspeed, ft/sec

α — angle of attack, deg

δ_a — tip-control deflection (positive direction indicated in fig. 1(a)), deg

θ_w — wing pivot angle measured between the wing and fuselage center lines, deg (fig. 1)

ρ — air density, slugs/cu ft

APPARATUS AND MODELS

Tests were made in the Langley high-speed 7- by 10-foot tunnel with a sting support system and an internally mounted six-component strain-gage balance. The geometric characteristics of the delta-wing—fuselage combination and of the diamond and rectangular plan forms tested are shown

in figure 1. The fuselage was constructed by adding a nose fairing to a balance housing available from a previous investigation and had a fineness ratio of about 8. The wings were made of 1/4-inch aluminum plate with the leading and trailing edges either rounded or beveled as shown in figure 1. The delta wing was pivoted on the fuselage at the two points labeled a and b in figure 1(a). The distance from the fuselage trailing edge to these points was 1/2 and 1/3 of the 80° delta-wing root chord, respectively. The delta wing was pivoted at two points on the wing, $0.58c_r$ and $0.67c_r$ (the centroid of area) along the wing center line. Both the diamond and rectangular wings, shown in figure 1(b), were pivoted at the centroids of their respective areas about point a on the fuselage.

The forward portion of the delta wing could be deflected about its center line to provide roll control. This "tip control" or "aileron" amounted to approximately 30 percent of the root chord and had an area of 8.95 percent of the total wing area. The direction of positive control deflection is indicated in figure 1(a). The delta-wing configuration was also tested with a horizontal tail made of 1/4-inch aluminum plate, shown in figure 1(b), and the wing pivoted 60° about $0.58c_r$.

TESTS

Tests were made in the Langley high-speed 7- by 10-foot tunnel at a Mach number of 0.40 and a dynamic pressure of about 213 pounds per square foot. The free-stream velocity corresponding to this Mach number was about 415 feet per second and the Reynolds number based on fuselage length was about 3×10^6. Force tests were made to determine the aerodynamic characteristics of the models through an angle-of-attack range from about -2° to about 24° with wing pivot angles from 0° to 109°. The delta wing was also tested with the tip control deflected at angles from approximately -40° to 30° about the wing center line; these tests were made through the angle-of-attack range with the wing pivoted at angles of 45° and 90°.

CORRECTIONS

The approximate jet-boundary corrections as determined by the methods of reference 3 were applied to the data as indicated by the following equations:

$$\alpha = \alpha_{tunnel} + 0.001C_L$$

$$C_D = C_{D_{measured}} + 0.05C_L^2$$

Blockage corrections were found to be negligible and therefore were not applied. The angle of attack was also corrected for deflection of the sting support system and strain-gage balance under load.

RESULTS

The aerodynamic characteristics in pitch of the delta-wing configuration are shown in figure 2(a) with the wing pivoted at the centroid of its area $(0.67c_r)$ and in figure 2(b) with the wing pivoted at $0.58c_r$. The aerodynamic characteristics of the diamond and rectangular plan forms are shown in figures 3 and 4, respectively. The aspect ratios of the three plan forms (based on the wing area and the wing dimension perpendicular to the airstream at a given pivot angle) are plotted against wing pivot angle in figure 5. Experimental lift-curve slopes are also plotted in figure 5 and compared with theoretical values based on these aspect ratios. The experimental values were obtained over the linear portions of the lift curves through $0°$ angle of attack, and the theoretical values were obtained from reference 4 by taking the sweep of the half-chord lines as $45°$ and $0°$ for wing-pivot angles of $45°$ and $90°$, respectively. Figure 6 shows the locations of the wing center of pressure in percent $\bar{c}$ for the three plan forms at various wing pivot angles as a function of lift coefficient. The effects of deflecting the tip control on the aerodynamic characteristics of the delta configuration are indicated in figure 7(a) for $\theta_w = 45°$ (fuselage pivot point a) and in figure 7(b) for $\theta_w = 90°$ (fuselage pivot point b). Figures 8(a) and 8(b) are cross plots of figures 7(a) and 7(b) showing rolling-moment coefficient as a function of control deflection at various angles of attack.

DISCUSSION

Lift and Drag Characteristics

Pivoting the three low-aspect-ratio wings resulted in systematic increases in lift-curve slope and corresponding reductions in drag, as might be expected from the increases in the aspect ratios of the plan forms. For the yawed delta plan form (figs. 2(a) and 2(b)) the stall occurred gradually as the angle of attack increased, and for wing pivot angles greater than $60°$ tended to occur first at an angle of attack of about $6°$ in the apex region of the wing. This tip stall was observed later by means of tuft studies made on a similar yawed-delta-wing configuration and is indicated in figures 2(a) and 2(b) by its effect on the rolling-moment characteristics at about $6°$ angle of attack. The lift for the delta plan form at the higher angles of attack was increased

by pivoting the wing from $\theta_w = 90^\circ$ to $\theta_w = 109^\circ$, indicating that some additional effects due to wing sweep were present. It should be kept in mind when evaluating the data for the delta-wing model that the wing was pivoted at two different points (a and b) on the fuselage and that some effects on the aerodynamic results due to this change in configuration are to be expected. These effects are believed to be small, however, because only slight differences can be noted between the pitching-moment data in the (a) and (b) parts of figure 2 for $\theta_w = 90^\circ$. Some aerodynamic improvements gained by pivoting the delta wing included an increase in untrimmed maximum L/D from about 5.2 at $\theta_w = 0^\circ$ to about 6.9 at $\theta_w = 109^\circ$ and an increase in the lift coefficient for maximum L/D from about 0.19 at $\theta_w = 0^\circ$ to about 0.39 at $\theta_w = 109^\circ$. It should be kept

in mind that, because of the preliminary nature of this investigation, the drag of the models was not made optimum. Considerable improvement over the L/D values obtained in this investigation would have been expected if more carefully designed wing-fuselage combinations had been used. For the diamond (fig. 3) and rectangular (fig. 4) wings the angle of attack at which stall occurred was successively reduced as the wing pivot angle was increased, a result which would be expected because of the increase in aspect ratio. Pivoting these plan forms produced larger increases in lift-curve slope and maximum L/D than were obtained for the delta wing; however, the maximum L/D values obtained were lower for the diamond wing than for the delta wing. The largest values of maximum L/D for the diamond and rectangular wings were obtained at $\theta_w = 45^\circ$; maximum L/D increased for the diamond from about 3.2 at $\theta_w = 0^\circ$ to about 5.9 at $\theta_w = 45^\circ$, and for the rectangle from about 3.0 at $\theta_w = 0^\circ$ to about 7.0 at $\theta_w = 45^\circ$. At $\theta_w = 90^\circ$, values of maximum L/D of about 4.6 and 6.4 were obtained for the diamond and rectangle, respectively. The lift characteristics of the diamond and rectangular plan forms were almost identical, except for the earlier stall of the diamond at $\theta_w = 90^\circ$. This earlier stall was to be expected because of the higher aspect ratio of the diamond at the higher pivot angles (fig. 5).

In general, the increases in lift-curve slope for the three plan forms agreed with results that would be expected from aspect-ratio and sweep considerations (fig. 5), and it is interesting to note that the theory of reference 4 could be used to predict lift-curve slopes for a plan form such as the yawed delta.

Longitudinal Stability

The data of figure 2(a) indicate that with no horizontal tail the delta-wing model was longitudinally unstable at all wing pivot angles with the center of gravity and wing pivot point at the centroid of wing

area. Increasing the wing pivot angle from 0° to 109° had little effect on the static longitudinal stability (as measured by the slopes of the pitching-moment curves) except at $\theta_w = 45^\circ$ where the instability was increased considerably at lift coefficients between about 0.3 and 0.4. Figure 6 shows that the delta-wing center of pressure was shifted forward to 34 percent of the unyawed mean aerodynamic chord by pivoting the wing from $\theta_w = 0^\circ$ to $\theta_w = 45^\circ$ (pivot point at $0.67c_r$), but was shifted rearward toward the pivot point by pivoting the wing from 45° to 90°. The forward center-of-pressure location at the higher lift coefficients for the 45° wing pivot angle would indicate that the sweptforward tapered left panel of the delta wing was not subject to tip stall and hence carried a good portion of the lift throughout the angle-of-attack range of the tests. Moving the wing pivot point forward to $0.58c_r$ (fig. 2(b)) made the model slightly more stable and also minimized the effects due to changes in pivot angle. As indicated by the results of reference 5, the effects due to changes in wing pivot angle might also be minimized by the addition of a horizontal tail at the rear of the fuselage.

A generally stable pitching-moment variation was obtained when a horizontal tail was added to the model with the delta wing at a 60° pivot angle (fig. 2(b)). Addition of a horizontal tail would probably be a practical method of obtaining longitudinal stability and trim for pivoted-wing configurations. The tail could be designed to retract into the fuselage, or else the rearward portion of the wing could be used as a tail with the remainder of the wing pivoted (as was simulated in this investigation), so as not to detract from the hypersonic performance of the vehicle.

The configurations with diamond and rectangular plan forms were longitudinally unstable when the wings were not yawed and with the center of gravity and pivot point at the centroid of area, but were made about neutrally stable by pivoting the wing (figs. 3 and 4).

Lateral Control

The yawed delta plan form produced fairly large rolling moments through the angle-of-attack range of the tests. It was thought that rolling moments could be minimized by properly balancing the areas of the right and left wing panels by changing the position of the pivot point on the wing. With the pivot point at the wing centroid (fig. 2(a)), rolling moments tended to become more positive with increasing angle of attack in the lower range, indicating a wing center of lift acting on the tapered left wing panel. With the pivot point at $0.58c_r$ (fig. 2(b)), rolling moments tended to become more negative with increasing angle of attack, indicating a shift in the wing center of lift to the opposite wing panel. Hence the pivot position for minimum roll should be somewhere between these two positions. For pivot angles above 60°, tip stall

caused the rolling moments to become rapidly more negative as the angle of attack increased above 6°. (See figs. 2(a) and 2(b).)

The tip control was effective in trimming the roll through the angle-of-attack range when the delta wing was pivoted at $0.67c_r$ to angles of 45° and 90°. (See figs. 7(a) and 7(b).) Negative control deflections produced noticeable reductions in lift coefficient, but these reductions were relatively small at the high lift coefficients for the negative deflections required for trim. Sizable pitching-moment increments were also produced by deflecting the tip control when $\theta_w = 45^O$. The cross plots of figures 8(a) and 8(b) indicate that, generally, control effectiveness was maintained at negative deflections up to -40° (the highest negative deflection of the investigation) but tended to fall off at the higher angles of attack at positive deflections greater than about 5°. From figure 2(b) it can be seen that for a wing pivot angle of 90° the rolling-moment coefficient produced at angles of attack above 12° would exceed the capability of the control as shown in figure 8(b). For this reason the centroid of wing area would probably be the best position for the delta-wing pivot point.

Both the diamond and rectangular plan forms gave out-of-trim roll when pivoted at the intermediate angles because one panel of the wing was swept forward and the other back. Some additional effects were to be expected because of the differences in stall characteristics between a sweptforward wing and a sweptback wing. It is believed, however, that static roll trim could also be obtained for these plan forms at a given pivot angle by the proper use of ailerons, as was the case with the delta plan form. This belief is substantiated by the results of reference 5 for a rectangular wing that was skewed as a unit in free flight to angles as high as 40° (corresponding to a θ_w range of 90° to 50°) without encountering serious stability and control difficulties. Lateral-control difficulties could probably be expected in the pivot-angle range from 0° to 50°, however, as was the case in reference 5, since a loss in aileron effectiveness could be expected in this range.

SUMMARY OF RESULTS

A wind-tunnel investigation has been made of a fuselage in combination with wings having low-aspect-ratio delta, diamond, and rectangular plan forms to determine the effects of pivoting the wings to extreme angles in the yaw direction to increase their aspect ratios. The results may be summarized as follows:

1. Low values of lift-curve slope and maximum lift-drag ratio inherent in the low-aspect-ratio plan forms were increased by pivoting the wings.

2. In general, the increases in lift-curve slope obtained by increasing the pivot angle followed trends expected from aspect-ratio considerations.
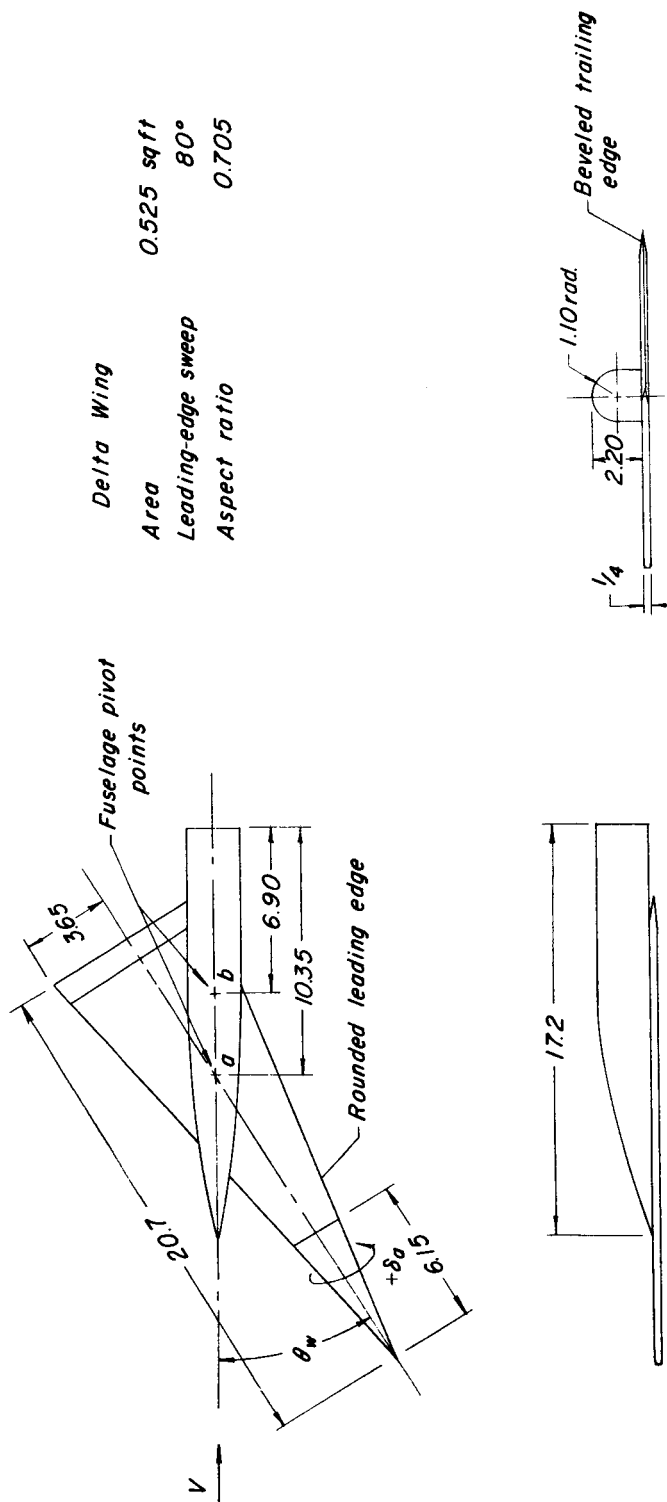
3. Increasing the wing-pivot angle θ_w from $0°$ to $109°$ generally had little effect on the static longitudinal instability of the delta-wing model with no horizontal tail, and a generally stable pitching-moment variation was obtained with $\theta_w = 60°$ when a horizontal tail was added. Pivoting the diamond and rectangular wings decreased the static longitudinal instability of these models with the center of gravity and wing pivot point at the centroid of area.

4. The delta wing which pivoted at 67 percent of the wing root chord could be trimmed laterally for wing pivot angles of $45°$ and $90°$ by means of a tip control.

Langley Research Center,
      National Aeronautics and Space Administration,
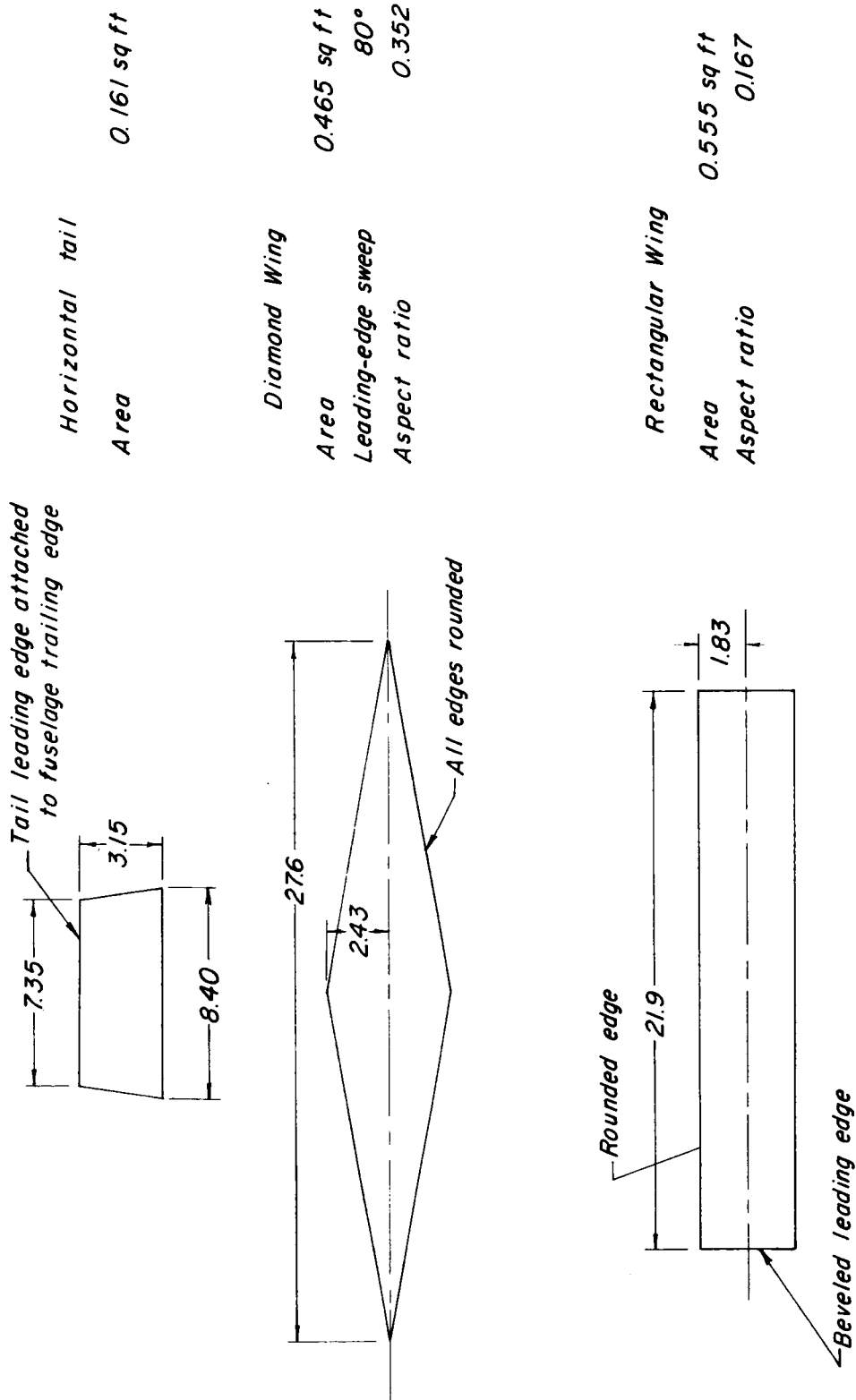   Langley Field, Va., November 9, 1959.

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2. McLellan, Charles H., and Dunning, Robert W.: Factors Affecting the Maximum Lift-Drag Ratio at High Supersonic Speeds. NACA RM L55L20a, 1956.

3. Gillis, Clarence L., Polhamus, Edward C., and Gray, Joseph L., Jr.: Charts for Determining Jet-Boundary Corrections for Complete Models in 7- by 10-Foot Closed Rectangular Wind Tunnels. NACA WR L-123, 1945. (Formerly NACA ARR L5G31.)

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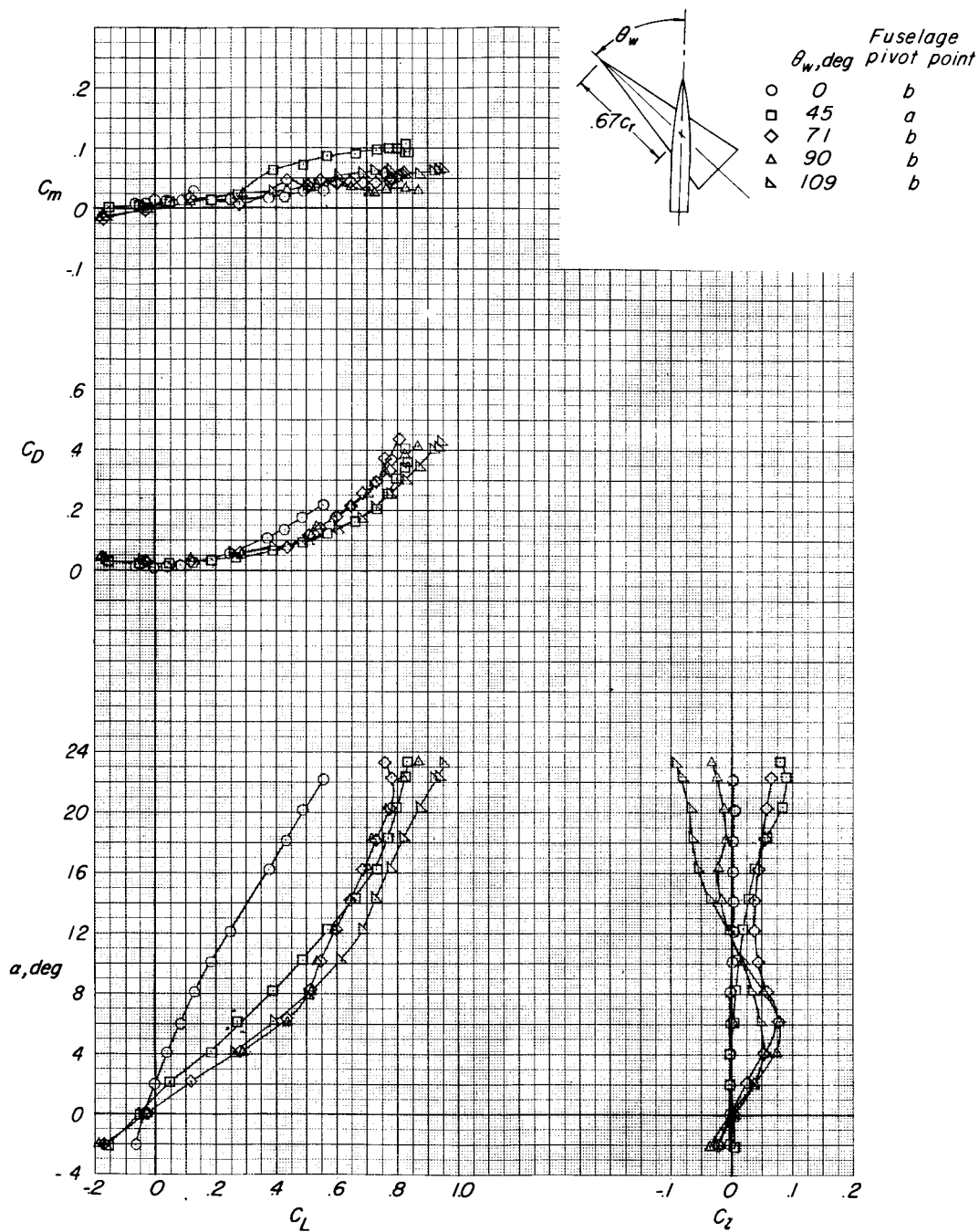
Delta Wing

Area   0.525 sq ft
Leading-edge sweep   80°
Aspect ratio   0.705

Beveled trailing edge

1.10 rad.

2.20

1/4

Fuselage pivot points

365

6.90

10.35

Rounded leading edge

20.7

6.15

$+\delta_a$

θ_w

V

a

b

17.2

(a) Fuselage and delta wing.

Figure 1.- Geometric characteristics of the models. All dimensions are in inches.

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Horizontal tail

Area .... 0.161 sq ft

Diamond Wing

Area .... 0.465 sq ft
Leading-edge sweep .. 80°
Aspect ratio 0.352

Rectangular Wing

Area .... 0.555 sq ft
Aspect ratio 0.167

Tail leading edge attached
to fuselage trailing edge

3.15

7.35

8.40

All edges rounded

27.6

2.43

1.83

21.9

Rounded edge

Beveled leading edge

(b) Diamond and rectangular wings.

Figure 1.- Concluded.

(a) Wing pivot point at $0.67c_r$.

Figure 2.- Aerodynamic characteristics in pitch for the delta-wing
model at various wing pivot angles.

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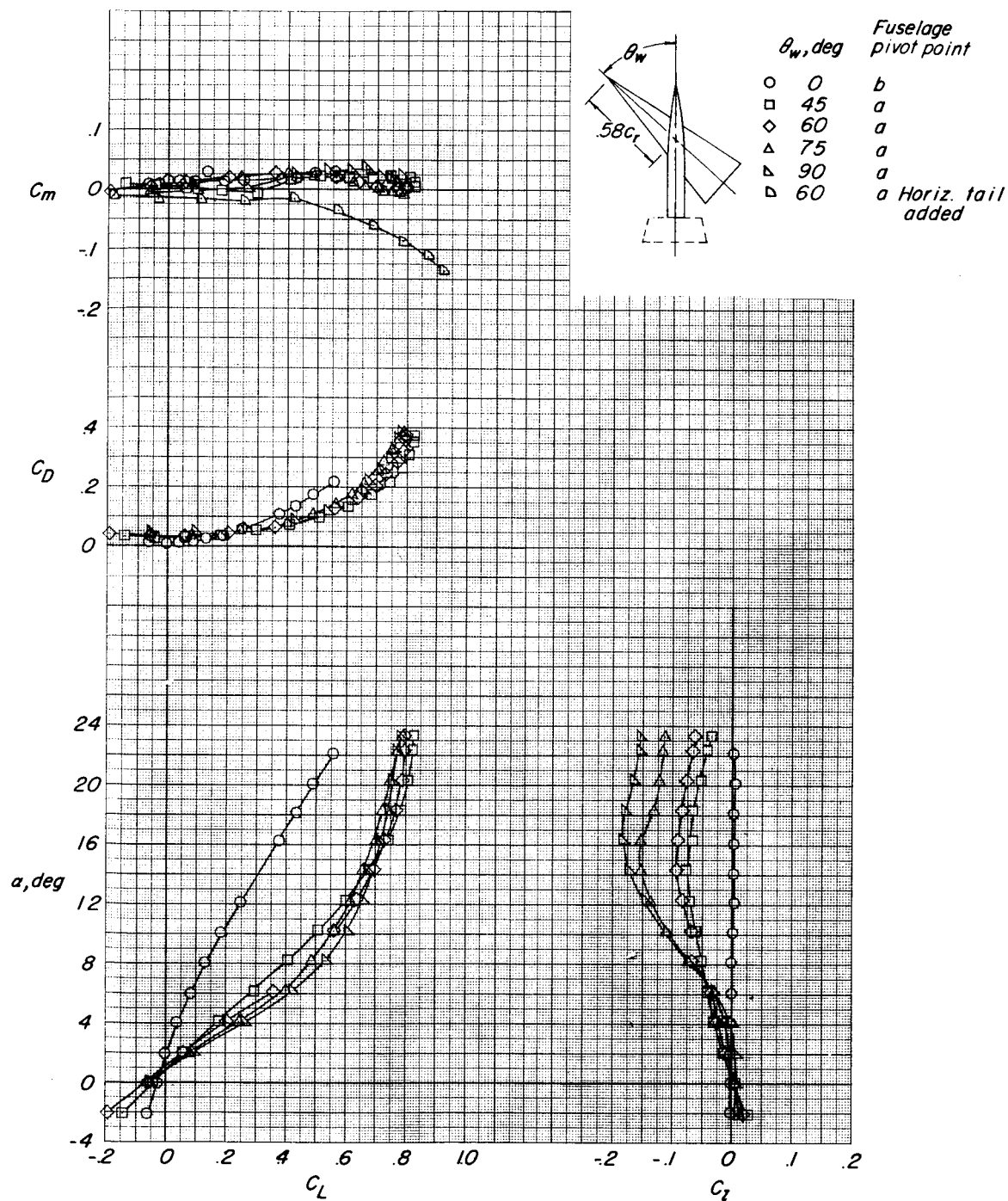
(b) Wing pivot point at $0.58c_r$.

Figure 2.- Concluded.
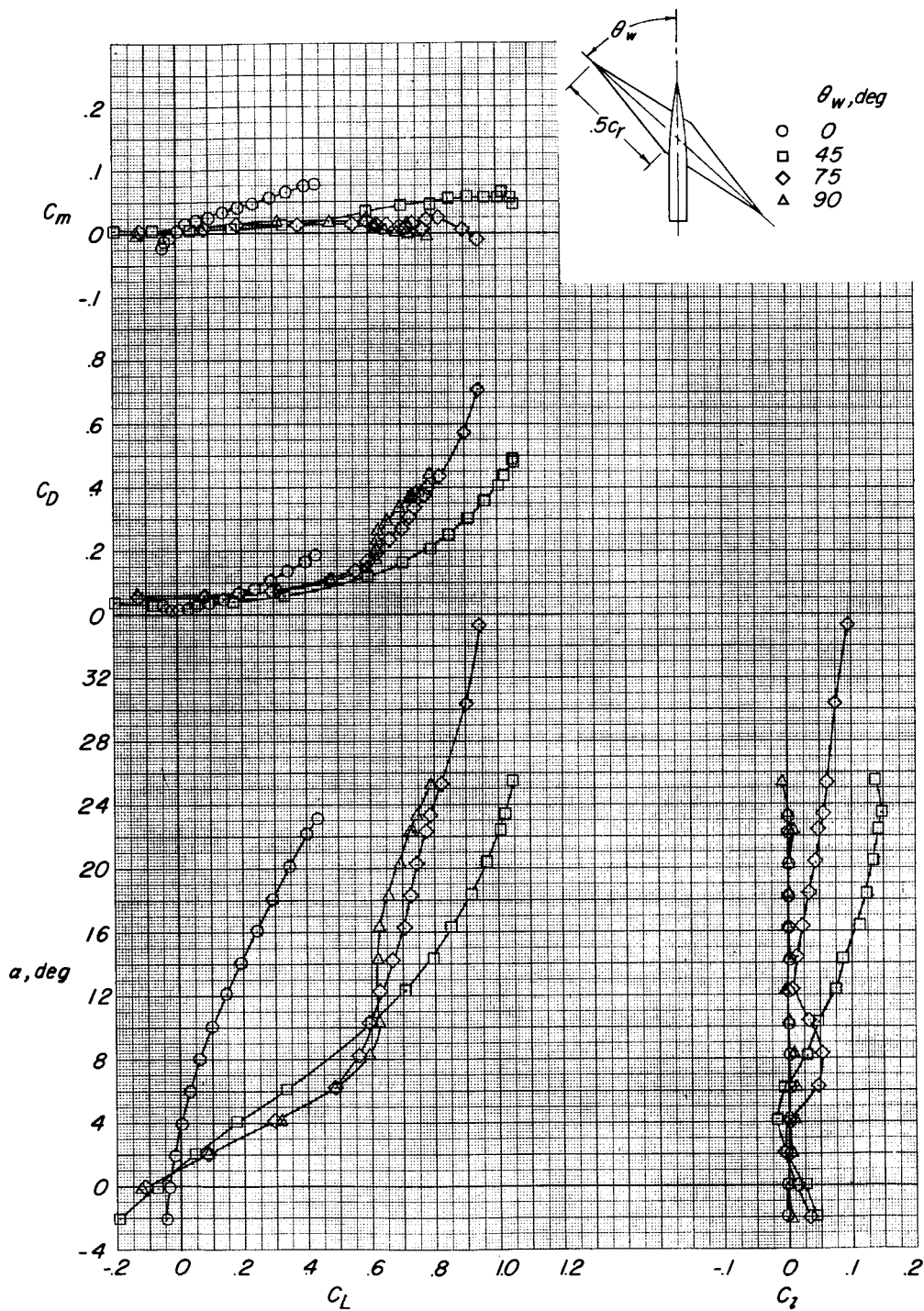
Figure 3.- Aerodynamic characteristics in pitch of the diamond-plan-form
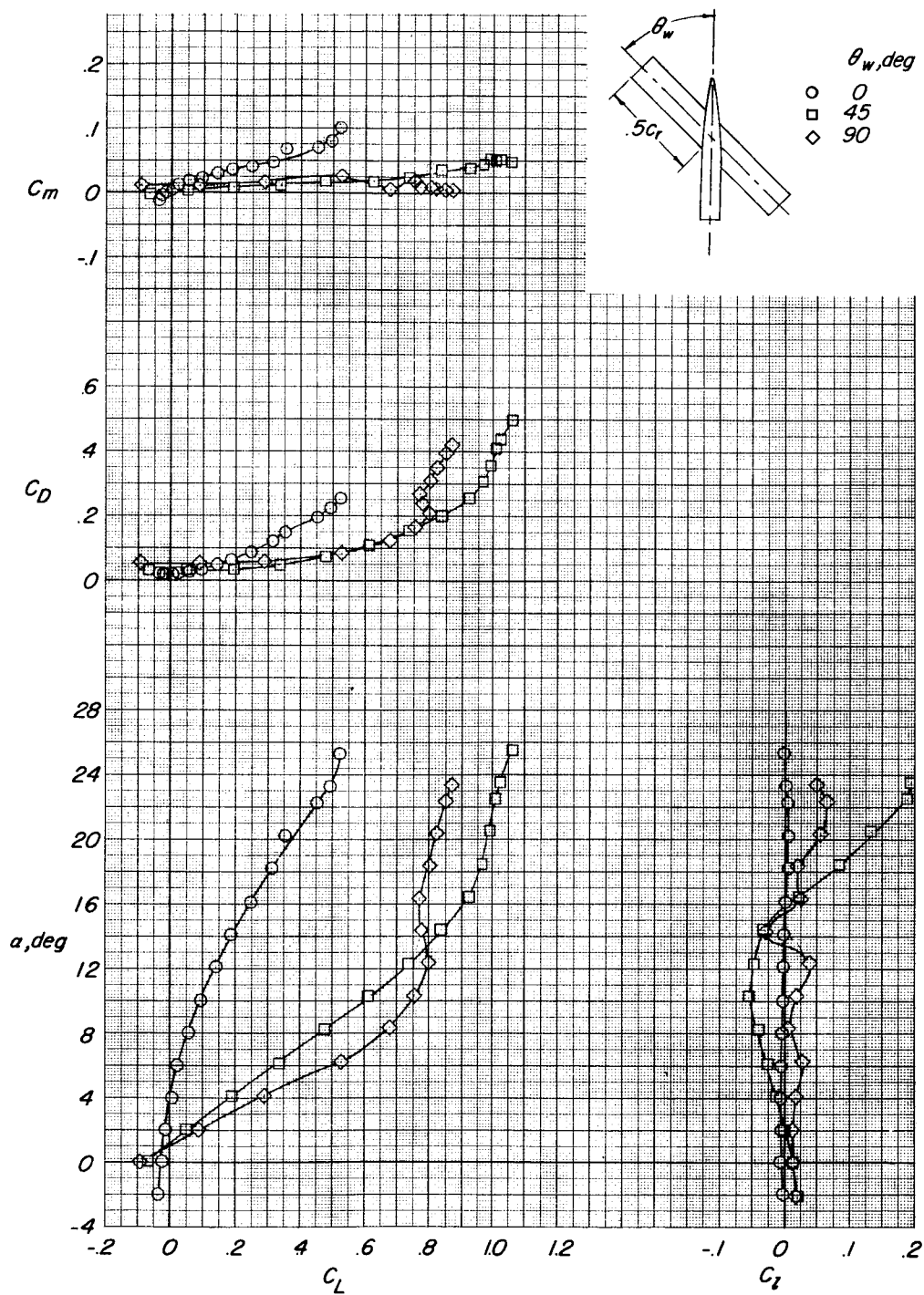model at various wing pivot angles.

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Figure 4.- Aerodynamic characteristics in pitch of the rectangular-plan-
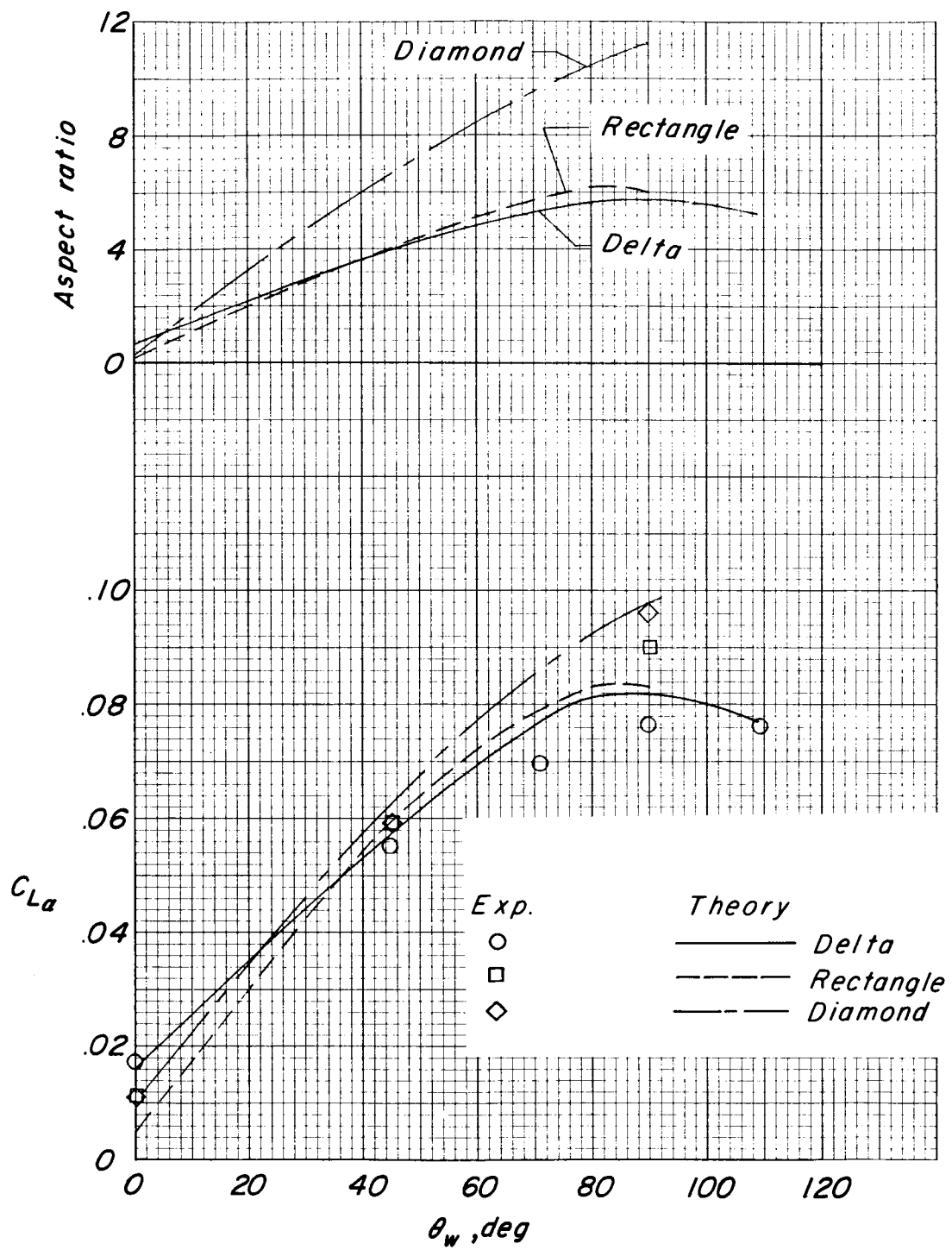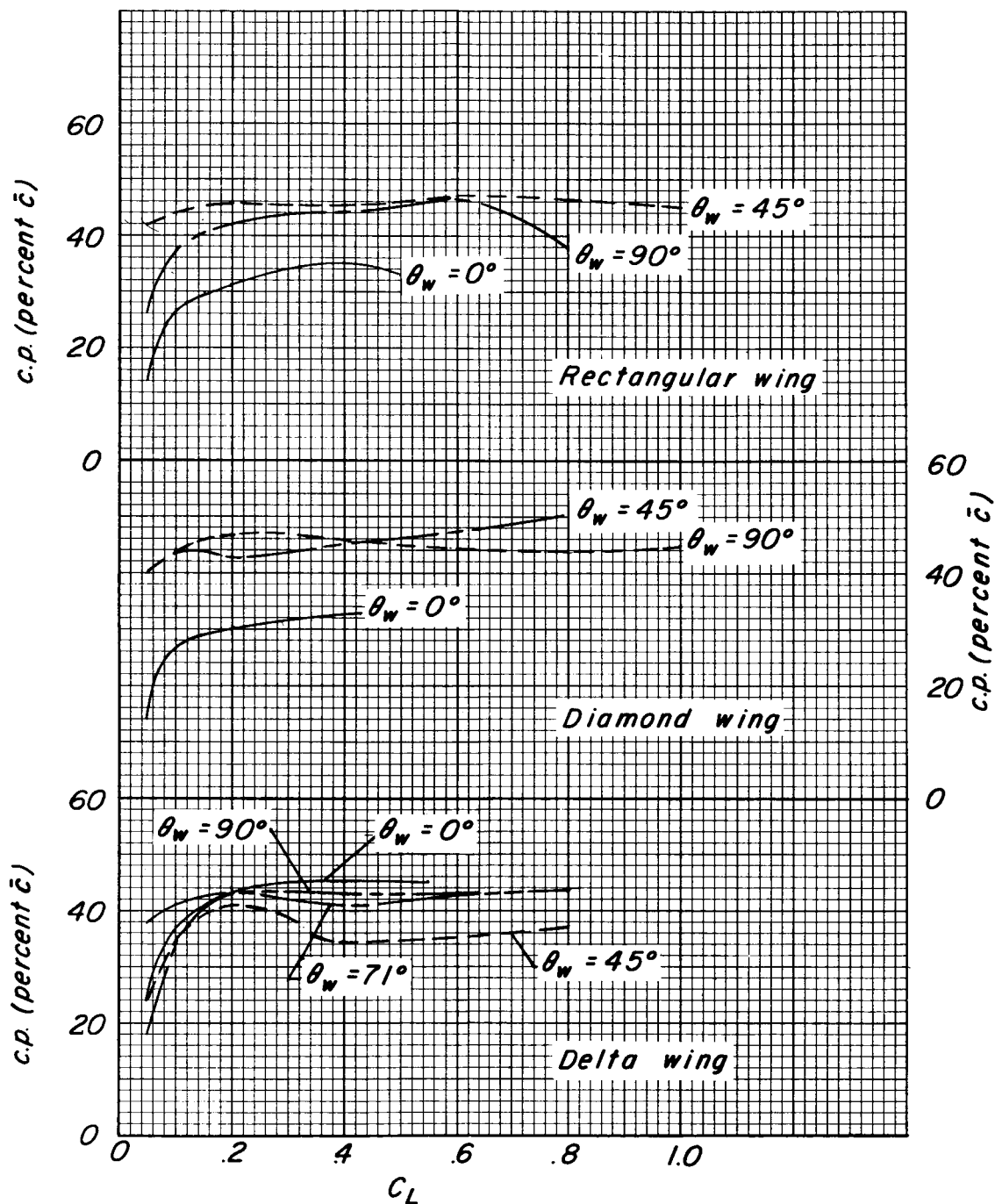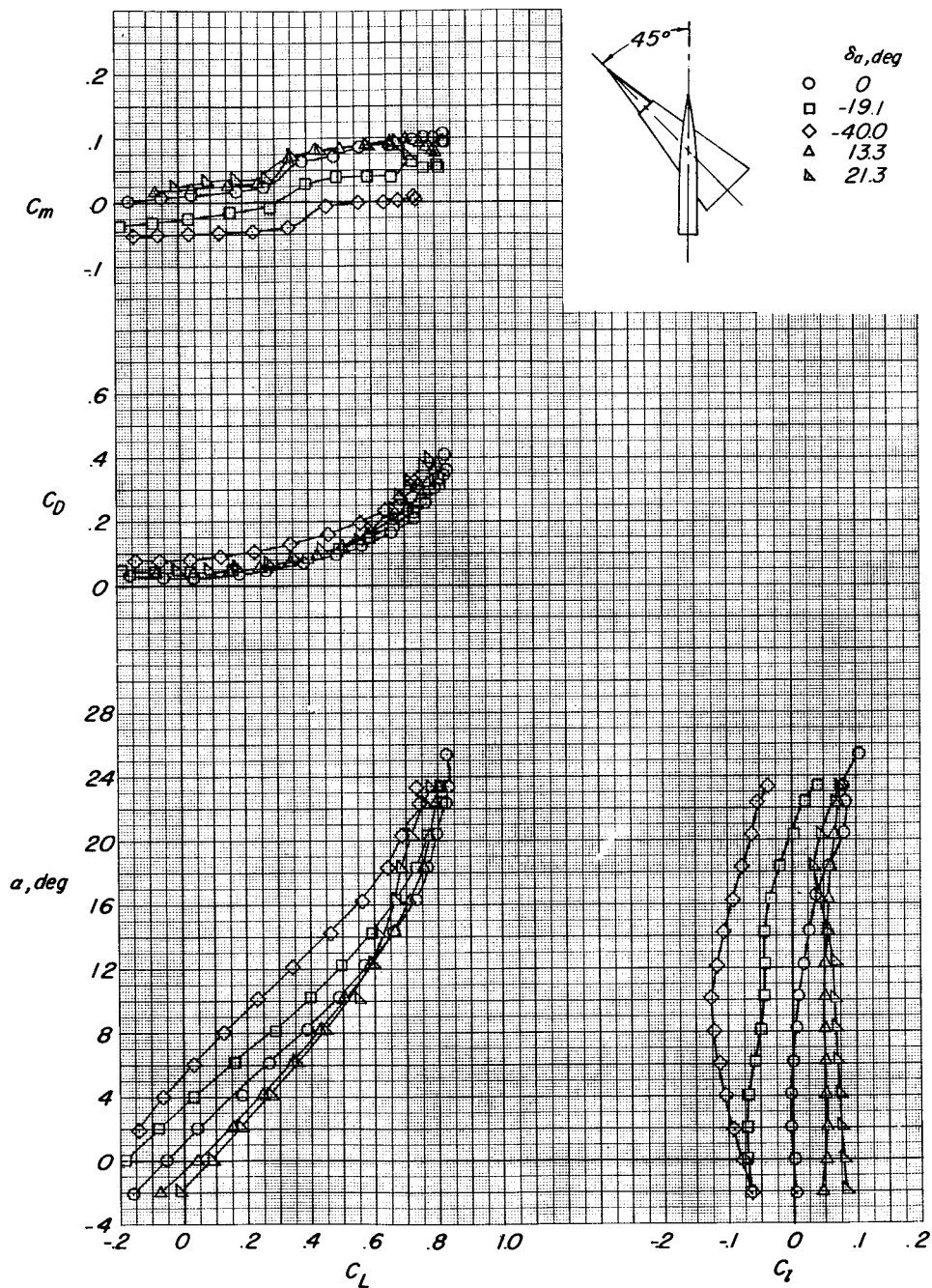form model at various wing pivot angles.

Figure 5.- Aspect ratio and lift-curve slope C_{L_α} as a function of wing pivot angle.

Figure 6.- Wing center-of-pressure location as a function of lift coef-
ficient for the models with delta, diamond, and rectangular wing at
various wing pivot angles.

(a) $\theta_w = 45°$; fuselage pivot point a.

Figure 7.- Effects of deflecting the tip control on the aerodynamic
characteristics of the delta-wing model. Wing pivot point at $0.67c_r$.
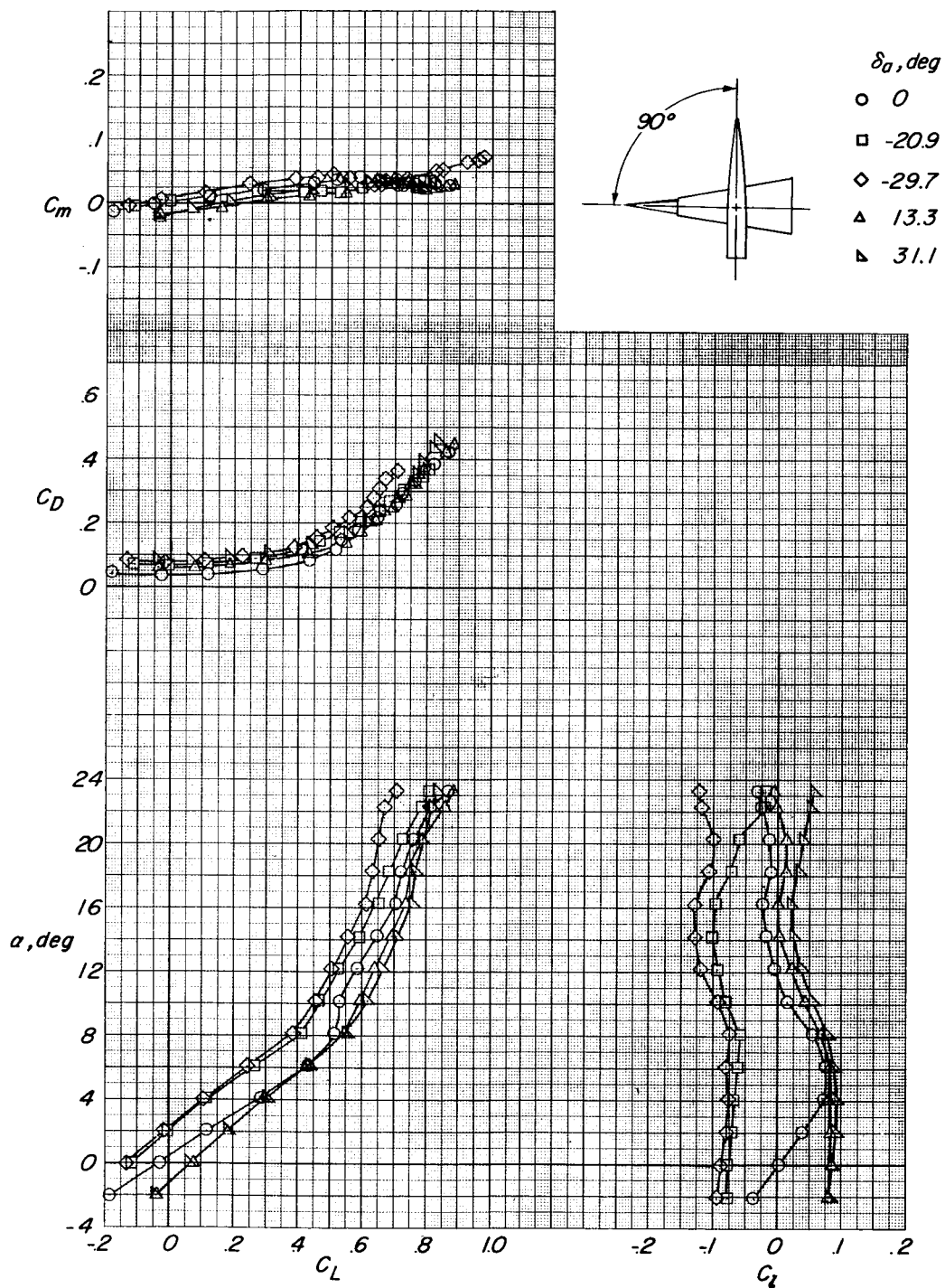
(b) $\theta_w = 90°$; fuselage pivot point b.

Figure 7.- Concluded.

a, deg
——— 0
------- 8
—·—·— 16
—··—··— 22
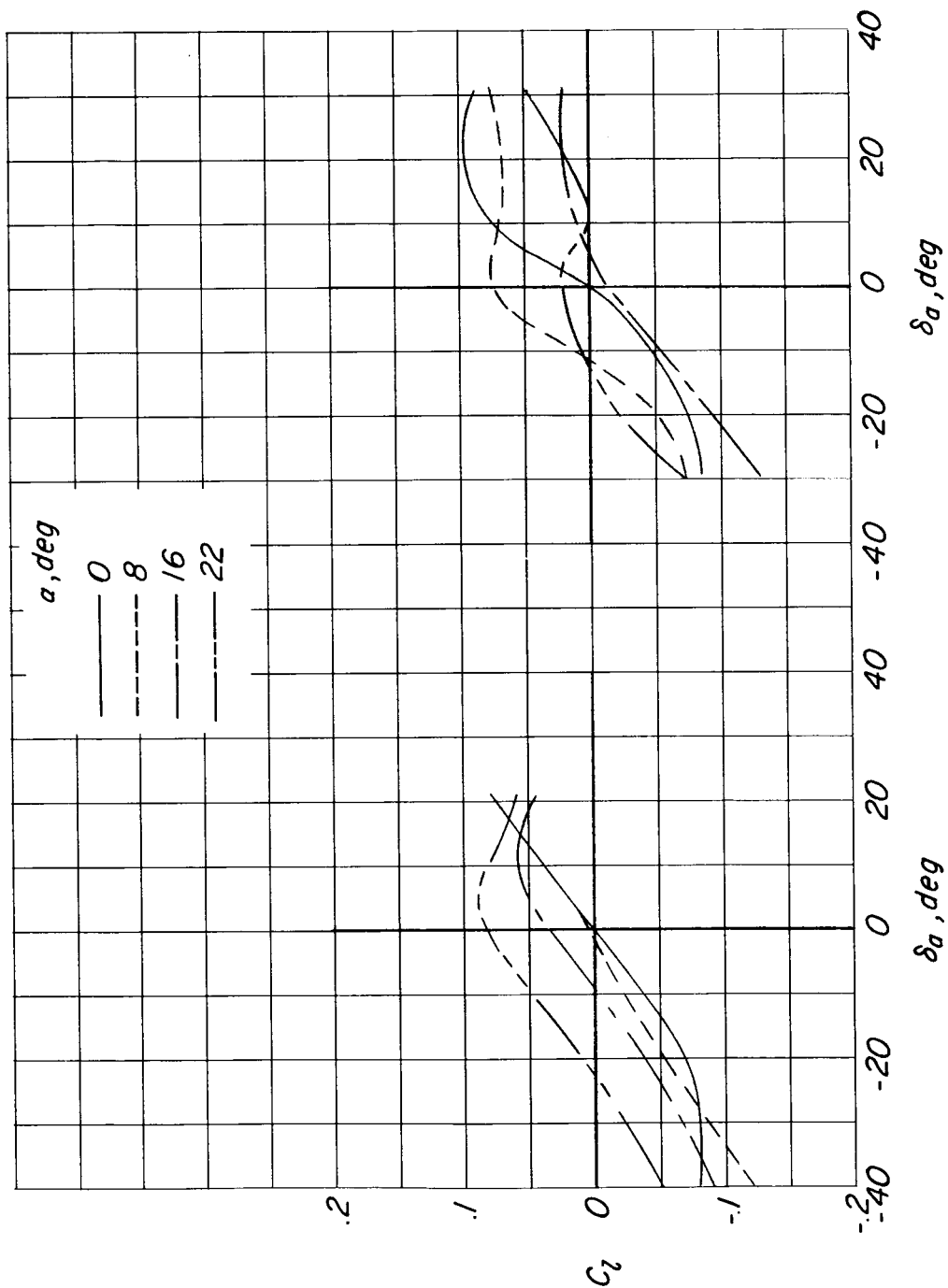
(a) $\theta_w = 45°$.

(b) $\theta_w = 90°$.

δ_a, deg

C_l

Figure 8.- Tip-control effectiveness.